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Review

Clinical updates on the effects of high intensity interval training (HIIT) exercise in people diagnosed with cancer. A systematic review and meta-analysis

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A B S T R A C T

Objectives: To provide an updated critical evaluation on the effectiveness of high intensity interval training (HIIT) on health outcomes amongst cancer survivors.
Design: Systematic review and meta-analysis.
Methods: A systematic search was conducted using databases CINAHL and Medline (via EBSCOhost platform), Scopus, Web of Science Core Collection, and the Cochrane Central Register of Controlled Trials. Randomised, controlled, exercise trials involving cancer survivors were eligible. Data on the effects of HIIT amongst individuals diagnosed with cancer at any stage were included. Risk of bias was assessed with the Mixed Methods Appraisal Tool (MMAT). Standardised mean differences (SMD) were calculated to compare differences between exercise and usual care. Meta-analyses (including subgroup analyses) were undertaken on the primary outcome of interest, which was aerobic fitness. Secondary outcomes were fatigue, quality of life, physical function, muscle strength, pain, anxiety, depression, upper-body strength, lower-body strength, systolic and diastolic blood pressure.
Results: Thirty-five trials from forty-seven publications were included, with intervention durations ranging between 4 and 18 weeks. Breast cancer participants were represented in the highest number of trials (n = 13, 37 %). Significant effects in favour of HIIT exercise for improving aerobic fitness, quality of life, pain and diastolic blood pressure were observed (SMD range: 0.25–0.58, all $p < 0.01$).
Conclusions: Participation in HIIT exercise was associated with higher retention and improvements in aerobic fitness, quality of life, pain and diastolic blood pressure. The present results provide updated contemporary evidence for clinicians (e.g., exercise physiologists and physiotherapists) to prescribe HIIT exercise for cancer survivors to improve health before, during and following treatment.

Practical implications

- Comprehensive meta-analysis of 35 trials (n = 1893 participants) using HIIT showed significant improvements across several physical outcomes in the cancer population.
- HIIT had a significant effect on improving aerobic fitness, fatigue, quality of life, pain and diastolic blood pressure compared to usual care.
- Non-significant effects were observed for physical function, muscle strength, anxiety, depression, fat mass, lean body mass, body fat (%) and systolic blood pressure using HIIT compared to the control groups.
- High retention rates were recorded at 95 % (79 % to 100 %) for the HIIT groups and 92 % (48 % to 100 %) for control groups, amongst different types of cancer populations.
- There were a total of 66 adverse events amongst participants allocated to HIIT exercise and 78 adverse events amongst participants allocated to comparator groups.
- Amongst the HIIT participants, 12 of the 66 adverse events were exercise-related and all were grade 1 (i.e., low severity; joint pain

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n = 7; leg pain n = 2; chest discomfort n = 1; light-headedness n = 1; muscle strain n = 1).

1. Introduction

There were approximately 19 million new cases of cancer globally in 2020, many will survive at least five years after their diagnosis,[1] resulting in a population with unique long-term needs as a consequence of their cancer treatments. Cancer and its treatments can result in adverse side effects for individuals, including reductions in physical function, fatigue, psychological distress, and quality of life.[2] Exercise is a widely accepted intervention to optimise physical, psychological and social aspects of holistic health and improve the wellbeing of those prior to, actively receiving, and recovering from cancer treatment.[3–6] The Clinical Oncology Society of Australia (COSA) recommends that exercise should be implemented as adjunctive care for patients with cancer, as a method to counteract the adverse effects of cancer and the associated treatments.[7]

Exercise can be beneficial throughout all stages of the cancer care continuum. Prior to treatment, exercise as a form of prehabilitation can lead to improved wellbeing and a reduction in the morbidity associated with cancer treatments.[5,8] Similarly, exercise throughout the cancer treatment experience has been demonstrated to preserve cardiovascular fitness, strength, and physical functioning, improve quality of life, and reduce fatigue.[9] Following treatment, cancer survivors may benefit from participating in exercise, with physical activity improving a range of physical and psychosocial outcomes.[10] Finally, participating in exercise can improve the quality of life, fitness, and fatigue for those receiving end of life palliative care.[11]

High intensity interval training (HIIT) exercise is characterised by alternating intense bursts of activity followed by short recovery periods consisting of rest or light exercise.[12] It focuses on exercising at, or near maximal oxygen uptake, and includes activities, such as, utilising treadmills and cycle ergometers. It has been demonstrated to result in benefits for cardiorespiratory fitness, skeletal muscle metabolism, vascular function, and other metabolic processes.[12]

There is growing evidence to demonstrate the effectiveness of HIIT exercise throughout the cancer care continuum, however the evidence is yet to be pooled and critically synthesised. Existing evidence provides promising outcomes following HIIT exercise interventions in this population.[13–16] The aim of this review was to further explore the effectiveness of HIIT exercise on aerobic fitness and various health outcomes, including safety and feasibility to update the evidence for the potential use of HIIT exercise in the cancer population. To the best of the authors knowledge, to date this is the most comprehensive review and meta-analysis of HIIT across the cancer care continuum.

2. Methods

2.1. Search strategy and study selection

This review was registered on PROSPERO registry (ID: CRD42022377720) and was conducted and reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement.[17] Studies of quantitative design were included. Relevant systematic reviews were examined for potentially relevant studies. The Participants, Intervention, Comparator, and Outcome (PICO) framework[18] was used to develop the eligibility criteria as follows: Participants: All adults (>18 years) diagnosed with cancer, regardless of stage, treatment regime, stage in the cancer care continuum, who participated in a HIIT exercise intervention were considered for inclusion. Intervention: Randomised controlled trials, including pilot and feasibility trials that evaluate the effect of HIIT exercise on individuals diagnosed with cancer with any type and stage were included. Exercise was defined as any form of planned, structured, and repetitive bodily movement undertaken to improve or maintain fitness, performance or health,[19] including aerobic, resistance, mixed-mode and other exercise. HIIT interventions that were between 80 and 100 % VO2max or predicted maximum heart rate (HRmax), interspersed with recovery exercise or no exercise between intervals, were eligible. Typically, HIIT is referred to as an intense aerobic-based intervention, it can be further sub-categorised into low- and high-volume HIIT, as well as 'sprint interval training' (SIT). Comparators: Studies that compared HIIT exercise, including different intensities and frequencies to control or usual care groups were included. Studies were excluded if; (a) they were non-RCTs, (b) they were not related to the outcomes of the review, (c) had no control/comparison group, (d) were animals or in vitro experiments, (e) were commentaries, conference abstracts, editorials or abstracts only, (f) cohorts other than cancer survivors, (g) reviews studies (any type) or (h) were clinical trial registrations.

Searches were carried out on 29th November 2022 by two of the authors, including an expert librarian, using the databases CINAHL and Medline (via EBSCOhost platform), Scopus, Web of Science Core Collection, and the Cochrane Central Register of Controlled Trials. Searches were based on key words relating to the study and Medical Subject Headings (MeSH) for 'High Intensity Interval Training' and 'Cancer' were used. To increase the inclusivity of search results, no date or language limiters were applied. See Supplementary 1 for full record of database searches. Reference lists of eligible full text articles were reviewed to ensure no studies were overlooked. All records were managed using Endnote X20 and uploaded to the Covidence systematic review management software for the removal of duplicates and screening according to pre-determined eligibility criteria.

2.2. Outcomes of interest

Meta-analyses (including subgroup analyses) were undertaken on the primary outcome of interest, which was aerobic fitness. Secondary outcomes of fatigue, quality of life, physical function, muscle strength, pain, anxiety, depression, upper-body strength, lower-body strength, systolic and diastolic blood pressure were also assessed.

Feasibility: participation and retention rates.

Safety: frequency and severity of adverse events were assessed using the Common Terminology Criteria for Adverse Events (Version 6.0) to categorise and classify the events.

2.3. Data extraction and management

Two review authors independently screened all titles and abstracts of identified records against the inclusion criteria. A third reviewer resolved all conflicts. The full text of all potentially eligible records was retrieved and screened independently by two authors. Any conflicts were resolved by a third reviewer or via discussion.

Study characteristics were extracted by one author using a standardised extraction form. A second author checked the data extraction for accuracy. Data were extracted and included in a table of "overview of included studies" and included: author and year, purpose of study, setting, country, sample size, participant demographic and clinical diagnosis, treatment types, study design, primary outcome measures, losses, retention and exclusion of participants.

The risk of bias was assessed for each included study using the Mixed Methods Appraisal Tool (MMAT).[20] Two authors independently assessed the studies and discussed any discrepancies with a third reviewer.

2.4. Statistical analysis

Meta-analyses were performed for aerobic fitness and health-related outcomes, which were analysed as continuous variables. Post-intervention means and standard deviations (SDs) were compared between the exercise and usual care groups. To facilitate comparisons across different measurement scales, standardised mean differences (SMDs) were used as the effect measures, calculated using RevMan software v5.3. Forest plots for each meta-analysis were generated using R statistical software v3.6.2. In cases where means and SDs were not reported in a paper ($n = 1$ trial), the authors were contacted ($n = 0$ responded), or formulas recommended by experts were utilised to estimate the means and/or SDs based on the available data (e.g., median, range, and sample size).[21] If a trial involved multiple instruments to assess an outcome, the instrument regarded as the gold standard or one with established validity and reliability was selected.

At the trial level, data from each meta-analysis were combined. Funnel plots were employed to assess publication bias, plotting SMDs against standard errors and examining for asymmetries or missing sections.[22] The following thresholds were used to describe effect sizes: less than 0.20 denoted a small effect, 0.20–0.50 indicated a medium effect, and greater than 0.50 represented a large effect.[23] Statistical significance was set at a P value less than 0.05. Cochran's Q test was utilised to evaluate statistical heterogeneity, and the proportion of overall outcome variability was examined using the I^2 statistic.[23,24] The I^2 values were interpreted as follows: $I^2 = 0$ %–29 %, no heterogeneity; $I^2 = 30$ %–49 %, moderate heterogeneity; $I^2 = 50$ %–74 %, substantial heterogeneity; and $I^2 = 75$ %–100 %, considerable heterogeneity.[24] Planned subgroup analyses were conducted to assess the effects of cancer type (prostate or testicular, lung, breast, colorectal, urological or bladder, leukaemia or haematological and mixed) and treatment status (pre-treatment or pre-surgery, post-treatment, during treatment and mixed [studies involved participants during and post-treatment]).

3. Results

3.1. Literature search

A total of 35 trials (comprising of 47 published papers) were included (see Fig. 1; Table 1). Quality appraisal results can be found in Supplementary 2. Most of the issues were related to blinding of outcome assessors to the intervention, which is common in exercise studies.

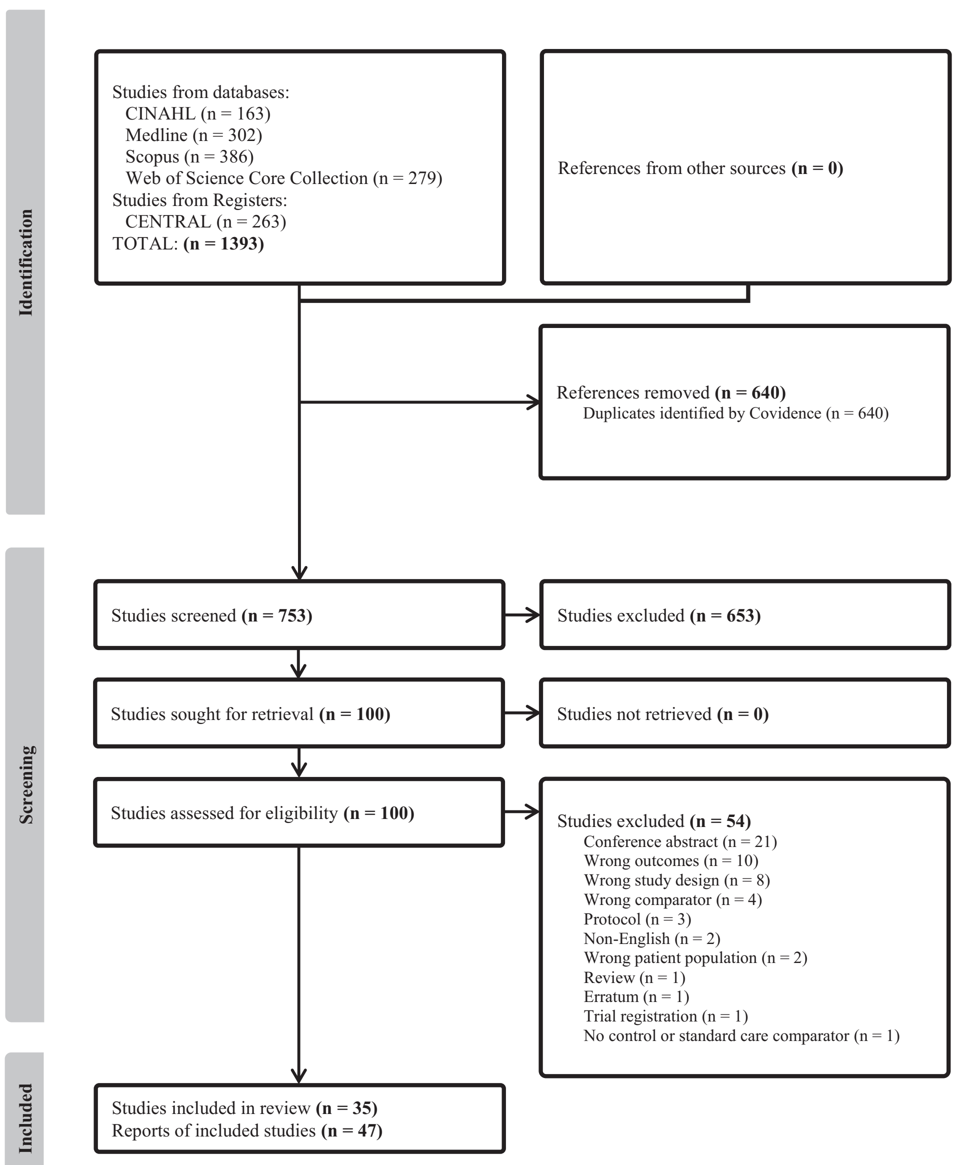

Fig. 1. Search strategy and article selection process according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Guidelines.[25]

Table 1
Overview of study characteristics (n = 35 trials).

Study	Sample size	Cancer type	Exercise duration and attendance
Adams et al., 2017[61]; Adams et al., 2018[62]	n = 63; >50	Type: testicular; treatment: single orchidectomy, radiotherapy & chemotherapy; stage: not specified	12 weeks; 99 % exercise session attendance
Alizadeh et al., 2019[38]	n = 52; >50	Type: breast; treatment: surgery, chemotherapy, radiotherapy & hormone; stage: non-metastatic & hormone-responsive	12 weeks; exercise adherence not reported
Ansund et al., 2021[39]	n = 88; >50	Type: breast; treatment: chemotherapy consisting of anthracyclines, taxanes, or a combination of the two	16 weeks; exercise adherence not reported
Baguley et al., 2022[40]	n = 23; <50	Type: prostate; treatment: radiation, chemotherapy, and ADT; stage: Gleason score 8.4 (1.1)	Weeks 12 to 20 of a 20-week intervention; 93.4 % exercise session attendance
Banerjee et al., 2018[26]	n = 60; >50	Type: bladder; treatment: surgery and chemotherapy; stage: not specified	Two exercise sessions per week prior to surgery; 83 % exercise session attendance
Bhatia et al., 2019[27]	n = 151; >50	Type: lung; treatment: prehabilitation for surgery; stage: early-stage (IIIA or less) non-small cell	Median of 8 sessions prior to surgery; 87 % exercise session attendance
Blackwell et al., 2020[28]	n = 40; <50	Type: urological; treatment; prehabilitation for treatment; stage: not specified	4 weeks; 84 % exercise session attendance
Devin et al., 2018[63]	n = 57; >50	Type: colorectal; treatment: surgery, chemotherapy, and radiotherapy; stage: I to IV	12 weeks; 99 % exercise session attendance
Dimeo et al., 1997[41]	n = 70; >50	Type: various; treatment: chemotherapy; stage: not specified	Hospitalisation duration of high-dose chemotherapy; exercise adherence not reported
Djurhuus et al., 2022[29]	n = 30; <50	Type: prostate; treatment: prehabilitation for radical prostatectomy	8 weeks; 100 % exercise session attendance
Dolan et al., 2016[64]	n = 33; <50	Type: breast; treatment: combinations of surgery, chemotherapy, radiation, and hormonal therapy; stage: early (I to IIIA)	6 weeks; exercise adherence not reported
Dunne et al., 2016[30]	n = 38; <50	Type: colorectal liver metastasis; treatment: prehabilitation for surgical resection; stage: IV	4 weeks; 18 of 19 patients completed 100 % of sessions
Egegaard et al., 2019[42]	n = 15; <50	Type: non-small cell lung cancer (NSCLC); treatment: concomitant chemoradiotherapy; stage: IIIa, IIIb, IV	7 weeks; 90 % exercise session attendance
Gonzalo-Encabo et al., 2022[43]	n = 30; <50	Type: breast; treatment: neoadjuvant and adjuvant anthracycline chemotherapy; stage: II and III	8 weeks; 82.3 % exercise session attendance
Hooshmand Moghadam et al., 2021[65]	n = 45; <50	Type: breast; treatment: surgery and concomitant chemotherapy or radiotherapy, hormonal therapy including tamoxifen and aromatase inhibitors	12 weeks; 86 % exercise session attendance
Hwang et al., 2012[44]	n = 24; <50	Type: non-small cell lung; treatment: targeted therapy including Iressa, Tarceva, and Afatinib; stage: IIIA, IIIB, and IV	8 weeks; 71.2 % exercise session attendance
Kang et al., 2021[35]; Kang et al., 2022a,[33]; Kang et al., 2022b[34]	n = 52; >50	Type: prostate, treatment: active surveillance; stage: T1c and T2a	12 weeks; 96 % exercise session attendance
Karenovics et al., 2017[31]; Licker et al., 2017[32]	n = 151: >50	Type: lung; treatment: surgery; stage: ASA classes 3 and 4	Prehabilitation before surgery; 69 % exercise session attendance
Lee et al., 2019a[46]; Lee et al., 2019b[45]; Lee et al., 2020[47]	n = 30; <50	Type: breast, treatment: anthracycline-based chemotherapy; stage: II & III	8 weeks; 82.3 % exercise session attendance
MacDonald et al., 2021[36]	n = 18; <50	Type: chronic lymphocytic leukaemia (CLL); treatment: no treatment; stage: Rai stage 0 or 1	12 weeks; 99 % exercise session attendance
MacVicar et al., 1989[48]	n = 45; <50	Type: breast; treatment: chemotherapy; stage: II	10 weeks; exercise adherence not reported
Mijwel et al., 2018a[49]; Mijwel et al., 2018b[50]; Mijwel et al., 2018c[51]; Mijwel et al., 2019[52]; Wiggenraad et al., 2020[53]; Hiensch et al., 2021[54]; Bolam et al., 2019[55]	n = 240; >50	Type: breast; treatment: chemotherapy; stage: I to IIIa	16 weeks; 83 % (RT–HIIT group) and 75 % (AT–HIIT group) exercise session attendance
Morielli et al., 2021[56]	n = 36; <50	Type: rectal; treatment: scheduled to receive standard long-course neoadjuvant chemoradiation (NACRT) consisting of radiation with concurrent chemotherapy, followed by total mesorectal excision; stage: III (64 % of participants)	Throughout NACRT (approximately 5 to 6 weeks); 82 % exercise session attendance
Northey et al., 2019[66]	n = 17; <50	Type: breast; treatment: post-treatment; stage: I to III	12 weeks; 78.7 % (HIIT group), 79.4 % (MOD group) exercise session attendance
Ochi et al., 2022[67]	n = 50	Type: breast; treatment: completed initial treatment except for hormone therapy; stage: I and IIa	12 weeks; 86 % exercise session attendance
Papadopoulos et al., 2021[37]	n = 18; <50	Type: prostate; treatment: active surveillance; stage: early stage	8 weeks; 96 % exercise session attendance
Persoon et al., 2017[68]	n = 109; >50	Type: hematologic malignancy; treatment: post autologous stem cell transplantation; stage: not reported	18 weeks; 86 % exercise session attendance
Piraux et al., 2021[57]	n = 78; >50	Type: prostate; treatment: radiotherapy; stage: not reported	5 or 8 weeks (depending on radiotherapy regime); 93.5 % exercise session attendance
Piraux et al., 2022[58]	n = 18; <50	Type: rectal; treatment: chemoradiotherapy; stage: II and III	5 weeks; 92 % exercise session attendance
Reljic et al., 2022[59]	n = 27; <50	Type: advanced; treatment: ongoing anticancer therapy; stage: III and IV	12 weeks; 92.5 % exercise session attendance
Samhan et al., 2021[69]	n = 60; >50	Type: breast; treatment: post-treatment; stage: I to III	8 weeks; adherence not reported
Schulz et al., 2018[70]	n = 26; <50	Type: breast; treatment: post and during treatment (chemotherapy, radiotherapy, hormone therapy)	6 weeks; 73 % completed 12 sessions, 20 % completed 11 sessions and 7 % completed 10 sessions
Sommer et al., 2016[60]	n = 40; <50	Type: non-small cell lung; treatment: surgical resection; stage: 1, 2, 3A	Duration – not reported; 67 % preoperative and 73 % postoperative exercise session attendance

Table 1 (*continued*)

Study	Sample size	Cancer type	Exercise duration and attendance
Toohey et al., 2018[14]	n = 75; >50	Type: breast (47), Ovarian (2), appendix (1), anal (1), cervical (1), liver (1), oesophageal (1), Melanoma (1), leiomyosarcoma (1), unknown primary (1); treatment: surgery, radiation therapy, hormone therapy, chemotherapy, no chemotherapy; stage: I and II (45), II to IV (12)	12 weeks; 76 % exercise session attendance
Toohey et al., 2020[16]	n = 17; <50	Type: breast; treatment: surgery, radiation, surgery plus chemotherapy, surgery plus radiation, surgery plus chemotherapy plus radiation	12 weeks; 78.7 % (HIIT group) and 79.4 % (moderate group) exercise session attendance

3.2. Study and participant characteristics

Participants with different types of cancers were included and a total of n = 1893 were represented in this review. Specifically, the studies were inclusive of participants diagnosed with breast (n = 13), testicular (n = 1), prostate (n = 5), bladder (n = 1), lung (n = 5), mixed (n = 4), colorectal (n = 4), and haematological (n = 2). An overview of the study characteristics is shown in Table 1, and individual study characteristics are provided in more detail in the data extraction table, Supplementary 3. Supplementary 4 shows the HIIT prescription used in each study and Supplementary 5 shows the outcome collection measures for each study.

3.3. Intervention characteristics

Intervention durations ranged between 4 and 18 weeks (average 10 weeks). A total of 35 intervention arms and 36 control arms were evaluated. Interventions were carried out during: i) prehabilitation (n = 7)[26–32]; ii) treatment naïve, including active surveillance (n = 5)[33–37]; iii) treatment (n = 15)[38–60]; iv) survivorship (n = 10)[14,16,61–69]; and v) a combination of active and completed treatment (n = 1)[70] stages. HIIT exercise training protocols varied across the interventions; a breakdown can be found in Supplementary Table 4.

3.4. Meta-analysis results

3.4.1. Aerobic fitness and other health outcomes of interest

Meta-analysis of 27 trials (n = 1282 participants) showed that HIIT had significant effects for improving aerobic fitness (SMD = 0.58 [95 % CI = 0.44, 0.72], $I^2 = 29$ %, $p < 0.01$) compared to control groups (Fig. 2). Significant effects of HIIT were also observed for fatigue (n = 13 trials, n = 766 participants, SMD = 0.36 [95 % CI = 0.21, 0.51], $I^2 = 0$, $p < 0.01$), quality of life (n = 13 trials, n = 699 participants, SMD = 0.25 [95 % CI = 0.06, 0.44], $I^2 = 24$, $p = 0.01$), pain (n = 7 trials, n = 454 participants, SMD = 0.27 [95 % CI = 0.08, 0.45], $I^2 = 0$, $p < 0.01$) and diastolic blood pressure (n = 7 trials, n = 213 participants, SMD = 0.55 [95 % CI = 0.18, 0.92], $I^2 = 39$, $p < 0.01$) compared to usual care (Figs. 2 and 3). No significant effects were observed for physical function, muscle strength, anxiety, depression, fat mass, lean body mass, body fat (%) and systolic blood pressure (SMD range = 0.00 to 0.35, all $p > 0.05$).

3.4.2. Subgroup analyses

Results for subgroup analyses for aerobic fitness are shown in Supplementary 6. Subgroup analyses showed no significant difference between cancer types (prostate or testicular, lung, breast, colorectal, urological or bladder, leukaemia or haematological and mixed) and treatment status (pre-treatment or pre-surgery, post-treatment, during treatment and mixed [studies involved participants during and post-treatment]) on changes in aerobic fitness (test for subgroup differences $p > 0.05$). For cancer type, significant improvements (all $p < 0.05$) in aerobic fitness were observed for prostate or testicular (SMD = 0.67 [95 % CI = 0.32, 1.02]), lung (SMD = 0.52 [95 % CI = 0.30, 0.74]), breast (SMD = 0.70 [95 % CI = 0.43, 0.96]), colorectal (SMD = 0.83 [95 % CI = 0.35, 1.31]) and mixed (SMD = 0.59 [95 % CI = 0.01, 1.17]). For treatment, improvements in aerobic fitness (all $p < 0.05$) were observed pre- (SMD = 0.47 [95 % CI = 0.29, 0.65]), post- (SMD = 0.84 [95 % CI = 0.54, 1.14]) and during treatment (SMD = 0.59 [95 % CI = 0.34, 0.84]).

Outcome	Intervention groups (n)	Participants (n)	Heterogeneity (%)	SMD (95% CI)	p
Aerobic fitness	27	1282	29	0.58 [0.44, 0.72]	<0.01
Fatigue	13	766	0	0.36 [0.21, 0.51]	<0.01
Quality of life	13	699	24	0.25 [0.06, 0.44]	0.01
Physical function	9	589	48	0.15 [-0.09, 0.39]	0.23
Muscle strength	10	403	75	0.35 [-0.09, 0.78]	0.12
Pain	7	454	0	0.27 [0.08, 0.45]	<0.01
Anxiety	6	274	0	0.00 [-0.24, 0.23]	0.97
Depression	8	334	23	0.18 [-0.08, 0.44]	0.18

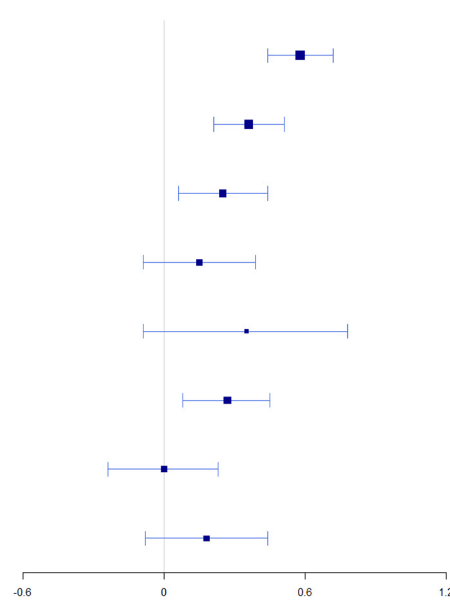

Fig. 2. Meta-analysis results for aerobic fitness, fatigue, quality of life, physical function, muscle strength, pain, anxiety and depression, comparing HIIT to control.

Outcome	Intervention groups (n)	Participants (n)	Heterogeneity (%)	SMD (95% CI)	p
Fat mass	8	255	61	0.21 [-0.21, 0.62]	0.33
Lean body mass	10	282	10	0.16 [-0.10, 0.42]	0.22
Body fat (%)	7	281	99	0.00 [-0.46, 0.46]	0.99
Systolic blood pressure	7	213	23	0.22 [-0.10, 0.54]	0.18
Diastolic blood pressure	7	213	39	0.55 [0.18, 0.92]	<0.01

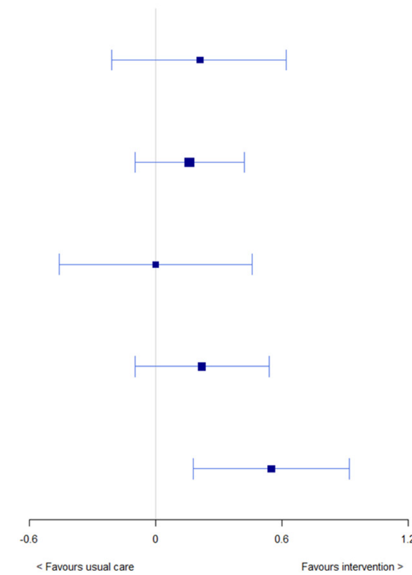

Fig. 3. Meta-analysis results for fat mass, lean body mass, body fat (%), systolic blood pressure and diastolic blood pressure, comparing HIIT to control.

3.4.3. Feasibility and safety

Median (range) recruitment rate was 52 % (6 % to 90 %) and median (range) retention rates were 95 % (79 % to 100 %) for HIIT and 92 % (48 % to 100 %) for the control conditions. There were a total of 66 exercise and non-exercise-related adverse events amongst participants allocated to HIIT (n = 12 grade 1 events; n = 1 grade 2 events; n = 32 grade 3 events; n = 15 grade 4 events; n = 6 grade 5 events) and 78 adverse events amongst participants allocated to control (n = 0 grade 1 events; n = 0 grade 2 events; n = 57 grade 3 events; n = 15 grade 4 events; n = 6 grade 5 events). Amongst the HIIT participants, 12 of the 66 adverse events were exercise-related and all were grade 1 (joint pain n = 7; leg pain n = 2; chest discomfort n = 1; lightheadedness n = 1; muscle strain n = 1).

4. Discussion

This systematic review and meta-analysis set out to provide an updated evaluation on the effectiveness of high intensity interval training (HIIT) on health outcomes amongst cancer survivors across the cancer care continuum. To date, this is the largest meta-analysis on HIIT in cancer, inclusive of thirty-five trials from forty-seven publications, representing 1893 participants with cancer. Broadly, existing HIIT intervention duration ranged between 4 and 18 weeks (average 10 weeks) and biased in favour of breast cancer participants. Significant effects in favour of HIIT exercise for improving aerobic fitness, quality of life, pain and diastolic blood pressure were observed which have important clinical translation implications.

These findings have several implications that could be considered in clinical practice when supporting people with cancer. Prehabilitation is an underutilised area of potential use of HIIT, and a critical time where people are preparing for major cancer surgeries and extensive treatment regimes. HIIT provided significant health benefits identified in this systematic review and could provide an efficient intervention to improve or maintain fitness prior to cancer treatments. It is useful to note that no significant effects were observed for lean mass, fat mass, muscle strength or physical function, which are often targeted outcomes for patients across the cancer continuum. The interval nature of HIIT, which is interspersed with rest periods, could mean that it would potentially be more tolerable for individuals who have less time or who are deconditioned. It could also be used in a lower more tolerable volume for people with more serious health challenges.

It is recommended that individual health assessments and preferences be taken into consideration when using HIIT prescription and session monitoring should occur, at least in the first instance (Fig. 4), this is in line with current cancer specific exercise recommendations.[71] Although HIIT may not be for everyone, as one size does not fit all, it should not be ruled out as something that cannot be offered. It has been reported to be more potent than moderate intensity training and even more enjoyable in some other populations such as overweight women and young adults.[72,73] Fig. 4 has therefore been developed based on the findings of this review, to assist clinicians practically, in implementing a HIIT programme for people with cancer.

4.1. Future recommendations

An important area for future research lies in the evaluation of different exercise intensities in the context of HIIT exercise for people diagnosed with cancer. A notable limitation of the current systematic review and meta-analysis was the inadequate reporting of exercise intensity in the included studies. Without detailed information on exercise intensity, it becomes challenging to ascertain the specific impact of varying intensities of HIIT on cancer-related outcomes. Understanding the optimal intensity of HIIT exercise for people diagnosed with cancer could help tailor exercise interventions to individual needs and potentially maximise the benefits derived from such interventions. Future studies should prioritise accurate and standardised reporting of exercise intensity to enable a more comprehensive evaluation of the effects of different intensities of HIIT exercise in the cancer population, across the entire cancer care continuum.

5. Conclusion

Exercise intensity and dose should be carefully considered when prescribing exercise for the cancer population because different personal effects can be achieved by adjusting these factors. This review and meta-analysis demonstrated that HIIT exercise significantly improved aerobic fitness, fatigue, quality of life, pain and diastolic blood pressure compared to the comparator groups and therefore should be considered when prescribing exercise for people diagnosed with cancer. HIIT's potent effect could be key to promptly improving the health of people undergoing significant

General recommendations (74)	Follow ACSM's relative and absolute contraindications for exercise.
Cancer specific exercise considerations (75)	**Absolute contraindications:** Bone pain During IV treatment: · febrile illness: 38°C/100.4°F– even if feeling well; · Resting SBP < 85 mmhg; · haemoglobin (hb): < 8.0g/dl or < 80.0 g/l (without CVD), < 9.0g/dl or 90g/l (with CVD) Platelets: < 20,000 µl Absolute neutrophils: < 0.5 × 109/L **Relative contraindications:** During IV treatment: · Vomiting or diarrhea within 24–36 hours; · Platelets: 20,000 – 50,000 µl (low impact, light intensity) *Relative contraindications can be suspended if exercise benefits outweigh risk. Proceed with caution.*
HIIT session guidelines	Intervention period - average 10 weeks (4-18 weeks)
	Sessions - 3 times per week – bike or treadmill – aim for regular exercise patterns
	Initial supervision by a qualified, experienced professional until confident and normal exercise responses. Supervision also recommended with lack of exercise exposure, complex health conditions and new symptom presentations
	Pre-exercise monitoring – HR, BP, BGL's (during treatment), blood counts, unusual symptoms – proceed if in normal ranges
	During exercise monitoring – HR, BP for the first session (minimum) to understand individuals' response
	Warm up - 5-10 minutes - 50% HRpeak
	HIIT's - 1 – 4 min at 75 – 90% HRpeak, 13-15 RPE with 1-4 minutes rest in between Start with shorter HIITs initially and longer rests in between, work with what is tolerated by the individual, progress as tolerated, and regress as needed
	Cool down - 10 minutes – 50% HRpeak
	Post exercise monitoring – HR and BP, until back to normal ranges

ACSM – American college of sports medicine; IV – intravenous; C – Celsius; F – Fahrenheit; SBP – systolic blood pressure; mmgH – millimetres of mercury; hb – haemoglobin; g – grams; dl – decilitre; gl – gigalitre; µl – microlitre; CVD – cardiovascular disease; L – litre; HR – heart rate; BP – blood pressure; BGL's – blood glucose levels; HIIT – high intensity interval training, RPE – rate of perceived exertion.

Fig. 4. Exercise recommendations, considerations and HIIT session guidelines for people with cancer [7475].
ACSM – American College of Sports Medicine; IV – intravenous; C – Celsius; F – Fahrenheit; SBP – systolic blood pressure; mmgH – millimetres of mercury; hb – haemoglobin; g – grams; dl – decilitre; gl – gigalitre; µl – microlitre; CVD – cardiovascular disease; L – litre; HR – heart rate; BP – blood pressure; BGL's – blood glucose levels; HIIT – high intensity interval training, RPE – rate of perceived exertion.

anti-cancer treatments. HIIT is currently underutilised in prehabilitation, during treatment and at end-of-life care for many diverse cancer populations. A low volume HIIT prescription could be tolerated well in people with health challenges, however, more research in this area is needed.

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CRediT authorship contribution statement

Concept/design: K. Toohey; systematic data search: M. Turner and M. Hunter; data screening and extraction: all listed authors; data analysis: K. Toohey and B. Singh; data interpretation: K. Toohey, M. Hunter and B. Singh; draft: K. Toohey; critical revision, writing contribution and approval: all listed authors.

Declaration of interest statement

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2023.09.020.

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Supplementary 1. Search strategy

Database searches were run on 29 November 2022 to identify relevant studies. To increase the inclusivity of the searches, no date range or language limiters were applied. Searches returned a total of 1,393 results. Search terms and number of results by individual database:

CINAHL (163)

((cancer* OR neoplasm* OR "cancer survivor*" OR oncolog* OR (MH "Neoplasms+")) AND ("high intensity interval training" OR "vigorous exercise*" OR "sprint interval training" OR "interval training" OR (MH "High-Intensity Interval Training")))

COCHRANE CENTRAL REGISTER OF CONTROLLED TRIALS (263)

#1	MeSH descriptor: [Neoplasms] explode all trees	111,738
#2	cancer* OR neoplasm* OR "cancer survivor*" OR oncolog*	242,895
#3	#1 OR #2	255,000
#4	MeSH descriptor: [High-Intensity Interval Training] explode all trees	893
#5	"high intensity interval training" OR "vigorous exercise*" OR "sprint interval training" OR "interval training"	3,954
#6	#4 OR #5	3,954
#7	#3 AND #6	289
	Limiter applied: Trials	263

MEDLINE (302)

((cancer* OR neoplasm* OR "cancer survivor*" OR oncolog* OR (MH "Neoplasms+")) AND ("high intensity interval training" OR "vigorous exercise*" OR "sprint interval training" OR "interval training" OR (MH "High-Intensity Interval Training")))

SCOPUS (386)

TITLE-ABS-KEY((cancer* OR neoplasm* OR "cancer survivor*" OR oncolog*) AND ("high intensity interval training" OR "vigorous exercise*" OR "sprint interval training" OR "interval training"))

WEB OF SCIENCE CORE COLLECTION (279)

TS=((cancer* OR neoplasm* OR "cancer survivor*" OR oncolog*) AND ("high intensity interval training" OR "vigorous exercise*" OR "sprint interval training" OR "interval training"))

Supplementary 2. Quality appraisal results (n = 35).

Quantitative Randomised Controlled Trials	**Item number of check list**						
	S1.	**S2.**	**2.1.**	**2.2.**	**2.3.**	**2.4.**	**2.5.**
Adams et al., 2017 (61); Adams et al., 2018 (62)	Y	Y	Y	Y	Y	Y	Y
Alizadeh et al., 2019 (38)	Y	Y	Y	Y	Y	Y	Y
Ansund et al., 2021 (39)	Y	Y	Y	Y	Y	U	Y
Baguley et al., 2022 (40)	Y	Y	Y	Y	Y	U	Y
Banerjee et al., 2018 (26)	Y	Y	Y	Y	Y	Y	Y
Bhatia et al., 2019 (27)	Y	Y	Y	Y	Y	U	Y
Blackwell et al., 2020 (28)	Y	Y	Y	Y	Y	Y	Y
Devin et al., 2018 (63)	Y	Y	Y	Y	Y	U	Y
Dimeo et al., 1997 (41)	Y	Y	Y	Y	Y	Y	Y
Djurhuus et al., 2022 (29)	Y	Y	Y	Y	Y	Y	Y
Dolan et al., 2016 (64)	Y	Y	U	Y	Y	U	U
Dunne et al., 2016 (30)	Y	Y	Y	Y	Y	Y	Y
Egegaard et al., 2019 (42)	Y	Y	Y	Y	Y	U	Y
Gonzalo-Encabo et al., 2022 (43)	Y	Y	Y	Y	Y	Y	Y
Hooshmand Moghadam et al., 2021 (65)	Y	Y	Y	U	Y	U	Y
Hwang et al., 2012 (44)	Y	Y	Y	Y	Y	Y	Y
Kang et al., 2021 (35); Kang et al., 2022a, (33); Kang et al., 2022b (34)	Y	Y	Y	Y	Y	N	Y
Karenovics et al., 2017 (31); Licker et al., 2017 (32)	Y	Y	Y	Y	Y	Y	Y
Lee et al., 2019a (46); Lee et al., 2019b (45); Lee et al., 2020 (47) ,	Y	Y	Y	Y	Y	U	Y
MacDonald et al., 2021 (36)	Y	Y	Y	Y	Y	U	Y
MacVicar et al., 1989 (48)	Y	Y	Y	Y	Y	U	Y
Mijwel et al., 2018a (49); Mijwel et al., 2018b (50); Mijwel et al., 2018c (51); Mijwel et al., 2019 (52); Wiggenraad et al., 2020 (53); Hiensch et al., 2021 (54); Bolam et al., 2019 (55)	Y	Y	Y	Y	Y	Y	Y
Morielli et al., 2021 (56)	Y	Y	Y	Y	Y	N	Y
Northey et al., 2019 (66)	Y	Y	Y	Y	Y	N	Y
Ochi et al., 2022 (67)	Y	Y	Y	Y	Y	Y	Y
Papadopoulos et al., 2021 (37)	Y	Y	Y	Y	Y	N	Y
Persoon et al., 2017 (68)	Y	Y	Y	Y	Y	Y	Y
Piraux et al., 2021 (57)	Y	Y	Y	Y	Y	N	Y
Piraux et al., 2022 (58)	Y	Y	Y	Y	Y	N	Y
Reljic et al., 2022 (59)	Y	Y	Y	Y	Y	Y	Y
Samhan et al., 2021 (69)	Y	Y	Y	Y	Y	Y	Y
Schulz et al., 2018 (70)	Y	Y	Y	Y	Y	N	Y
Sommer et al., 2016 (60)	Y	Y	Y	U	Y	U	Y

Toohey et al., 2018 (14)	Y	Y	Y	Y	Y	U	Y
Toohey et al., 2020 (16)	Y	Y	Y	Y	Y	U	Y

S1. Are there clear research questions, S2. Do the collected data allow to address the research questions, 2.1. Is randomisation appropriately performed, 2.2. Are the groups comparable at baseline, 2.3. Are there complete outcome data, 2.4. Are outcome assessors blinded to the intervention provided, 2.5. Did the participants adhere to the assigned intervention.

Supplementary 3. Data extraction (study purpose, participant characterisations, response rate, design, and data collection timepoints).

Author/ Year	Purpose	Sample size/mean age (SD, years), gender	Participants (Cancer type, cancer stage, treatment)	Response Rate; attrition/ adherence; adverse events	Design	Time Points
Adams et al., 2017 (61); Adams et al., 2018 (62)	Effects of HIIT on markers of CVD risk factors and mortality in testicular cancer survivors.	Participants: 63 Age: 43.7y (10.8) Gender: male	Type: Testicular Stage: not specified Treatment: Single orchidectomy, radiotherapy & chemotherapy	Response rate: 63/948 Adherence: 99% exercise session attendance Adverse events: nil	Phase II randomised clinical trial	Baseline and 12 week follow up
Alizadeh et al., 2019 (38)	To show that patients who perform the HIIT during hormone therapy would show improvements in low-grade inflammation.	Participants: 52 Age: 49.2 (9.7) Gender: Female	Type: Breast Stage: Non-metastatic & hormone-responsive Treatment: Surgery, Chemotherapy, Radiotherapy & hormone	Response rate: 52/456 Adherence: not reported Adverse events: not reported	Single-center randomized controlled trial including two study arms.	Baseline and 12 weeks
Ansund et al., 2021 (39)	The effects of exercise on cardiotoxicity by assessing fitness and biomarkers over the intervention and into survivorship.	Participants: 88 Age: RT HIIT 53.5y (10.2), AT HIIT 53.7 (7.9) Gender: Female	Type: Breast Stage: I–IIIa Treatment: Chemotherapy consisting of anthracyclines, taxanes, or a combination of the two	Response rate: Post Hoc analysis on participants who attended 60% of exercise sessions (88 out of the 240 women) Adherence: 60% (benchmark) Adverse events: Nil	Post-hoc exploratory analysis	Baseline, 16 weeks and 1 year
Baguley et al., 2022 (40)	Examine the combined effects of a MED-diet and HIIT on cardiorespiratory fitness, body composition and quality of life in prostate men treated with ADT.	Participants: 23 Age: 65.9 (7.8) Gender: Male	Type: Prostate Stage: Gleason score 8.4 (1.1) Treatment: Radiation, chemotherapy & ADT	Response rate: 41% Adherence: Nutrition 81% reaching 75% at 12 weeks and 66% at 20 weeks, only 1 drop out in each group Adverse events: None	A two-arm randomised controlled trial	20 weeks MED – diet plus eight weeks of Med – diet with HIIT
Banerjee et al., 2018 (26)	Investigate the feasibility of vigorous intensity aerobic interval exercise in bladder cancer patients prior to radical cystectomy.	Participants: 60 Age: 71.60 (6.80) Gender: seven females, 53 males	Type: Bladder Stage: NA Treatment: Surgery and chemotherapy	Response rate: 53.5% Adherence: 83% Adverse events: None	Randomised feasibility trial.	Two exercise sessions per week prior to surgery
Bhatia et al., 2019 (27)	Examine the effect of prehabilitation in patients	Participants: 151 Age: 64 (11.5)	Type: Lung Stage: Early-stage (IIIA or less) non-small cell	Response rate: 92% Adherence: 87%	Randomised controlled trial	Median of 8 sessions prior to surgery

	diagnosed with lung cancer.	Gender: male (60%)	Treatment: prior to surgery	Adverse events: none		
Blackwell et al., 2020 (28)	To assess the efficacy of high-intensity interval training (HIIT) for improving cardiorespiratory fitness (CRF) in patients awaiting resection for urological malignancy within four weeks.	Participants: 40 Age:72 (mean) Gender: male (39), female (1)	Type: Urological Stage: NA Treatment: Prior to treatment	Response rate: NA Adherence: 84% Adverse events: none	Parallel randomised control trial	3-4 times per week for 4 weeks.
Devin et al., 2018 (63)	Describe the time course of changes in cardiorespiratory fitness and body composition in responses to an 8-week (1) MICE intervention, (2) HIIE intervention of equivalent frequency, and (3) a HIIE - T intervention utilizing a tapered frequency prescription in a cohort of colorectal cancer survivors.	Participants: 57 Age: 60.7 Gender: 50 female, 37 male	Type: colorectal Stage: I-IV Treatment: Surgery, chemotherapy, and radiotherapy	Response rate: 88% Adherence: 99% Adverse events: none	Randomised clinical trial	Baseline, 4, 8, and 12 weeks
Dimeo et al., 1997 (41)	The effects of aerobic exercise on the loss of physical performance and on the incidence and severity of complications in patients undergoing high-dose chemotherapy (HDC) followed by autologous peripheral blood stem cell transplantation (PBSCT).	Participants: 70 Age: 39 (10) Gender: Female	Type: various Stage: not reported Treatment: Chemotherapy	Response rate: 80% Adherence: not reported Adverse events: none	Randomised clinical trial	30 minutes cycling per day during hospitalisation, tests at baseline and discharge
Djurhuus et al., 2022 (29)	Examine the effects of high-intensity aerobic exercise training four-times weekly in men with early-stage localised prostate cancer before radical prostatectomy on tumour NK-cell infiltration, physiological,	Participants: 30 Age: 63 (IQR 57, 67) Gender: Male	Type: Prostate Stage: early Treatment: prehabilitation before radical prostatectomy	Response rate: 104 patients screened; 30 patients enrolled Adherence: 100% attendance at exercise sessions Adverse events: N/A	Randomised controlled trial	Baseline and follow-up

	and patient-reported outcomes.					
Dolan et al., 2016 (64)	Investigate the effect of a 6-week exercise intervention on the change in aerobic capacity between aerobic interval training, continuous moderate training, and a control group.	Participants: 33 Age: 56.2 (9) Gender: Female	Type: Breast Stage: early (I-IIIA) Treatment: Combinations of surgery, chemotherapy, radiation, and hormonal therapy	Response rate: 59 patients screened; 36 patients enrolled Adherence: not reported, missed sessions due to work or family engagements Adverse events: N/A	Pilot randomised controlled trial	Baseline, 6-week follow-up
Dunne et al., 2016 (30)	Assess the feasibility of a 4-week supervised preoperative exercise programme in patients awaiting surgery for colorectal liver metastasis, assessing the impact on preoperative fitness, QoL, perioperative outcomes and postoperative course.	Participants: 38 Age: 61 (IQR 56-66) Gender: Male 13; Female 7	Type: Colorectal liver metastasis Stage: IV Treatment: prehabilitation for surgical resection	Response rate: 193 patients screened, 38 patients enrolled Adherence: 18 of 19 patients completed 100% of sessions, one patients missing two sessions Adverse events: N/A	Randomised controlled trial	Baseline, 4-week follow-up
Egegaard et al., 2019 (42)	Assess the feasibility of intervention, and examine the effect on cardiopulmonary endpoints, quality of life, anxiety, depression and cancer-related side effects in patients receiving concomitant chemoradiotherapy.	Participants: 15 Age: 64 (±5.8) Gender: n=5 female	Type: Non-small cell lung cancer (NSCLC) Stage: IIIa n=3; IIIb n=4; IV n=1 Treatment: concomitant chemoradiotherapy	Response rate: n=34 screened Adherence: 90.0% attendance rate to exercise Adverse events: N/A	Randomised controlled trial	Baseline, 7-week follow-up
Gonzalo-Encabo et al., 2022 (43)	Determine the effects of an 8 weeks HIIT intervention on metabolic syndrome and associated biomarkers in patients with breast cancer undergoing anthracycline chemotherapy.	Participants: 30 Age: 46.9 (±9.8) (mean of both groups) Gender: female	Type: Breast Stage: II (30%), III (63%) Treatment: neoadjuvant and adjuvant anthracycline chemotherapy	Response rate: n=58 screened, 30 enrolled Adherence: 82.3% (average of 19.2 of 24 sessions) Adverse events: N/A	Pilot randomised controlled trial	Baseline, 8-week follow-up
Hooshmand Moghadam et al., 2021 (65)	Investigate the role of HIIT vs. MICT in postmenopausal breast cancer	Participants: n=45 Age: 57 (±1) (all participants)	Type: Breast Stage: I n=4; II n=4; III n=5 Treatment: surgery n=2;	Response rate: n=140 screened, n=45 enrolled	Randomised controlled trial	Baseline, 12-week follow-up

	survivors on cytokines (IL-6, IL-8, IL-10, and TNF-α) and adipokines (leptin and adiponectin); evaluate the effects of HIIT vs. MICT on body composition and physical fitness outcomes as related to inflammatory markers.	Gender: female	surgery + chemotherapy n=4; surgery +radiation n=4; surgery + chemotherapy + radiation n=3. Hormonal therapy: tamoxifen n=6; aromatase inhibitors n=5; none n=2	Adherence: 86% (both HIIT and MICT groups) Adverse events: N/A		
Hwang et al., 2012 (44)	Investigate whether 8 weeks of exercise training improves exercise capacity, as assessed by VO_{2peak}, and other related factors in patients with non-small cell lung cancer receiving targeted therapy.	Participants: n=24 Age: 61.0 (±6.3) Gender: male n=5 (38.5%)	Type: non-small cell lung Stage: IIIA n=1; IIIB n=2; IV n=10 Treatment: targeted therapy: Iressa n=5 (38.5%); Tarceva n=7 (53.8%); Afatinib n=1 (7.7%)	Response rate: n=44 screened, n=24 enrolled Adherence: mean adherence = 71.2%; n=9 participants attended ≥75%; n=3 attended 100% of sessions Adverse events: N/A	Randomised controlled trial	Baseline, 8-week follow-up
Kang et al., 2021 (35); Kang et al., 2022a, (33); Kang et al., 2022b (34)	Explore exercise motivation in men with prostate cancer undergoing active surveillance participating in a randomised exercise trial.	Participants: n=52 Age: 63.9 (±7.5) Gender: male	Type: prostate Stage: T1c n=24 (92%); T2a n=2 (8%) Treatment: active surveillance	Response rate: n=361 screened; n=52 randomised Adherence: 96% attendance with 100% adherence to intensity and duration Adverse events: 8 participants (15%) reported aggravation of previous medical issues (joint pain n=6, chest discomfort n=1, light headedness n=1) that were potentially related to HIIT	Randomised controlled trial	Baseline, 12-week follow-up
Karenovics et al., 2017 (31); Licker et al., 2017 (32)	Evaluated the impact of adding rehabilitation (Rehab) with high-intensity interval training (HIIT) before lung cancer surgery to enhance cardiorespiratory fitness and improve long-term	Participants: 151 Age: 64 (11) Gender: 91 male, 60 female	Type: Lung Stage: ASA classes 3 and 4 Treatment: Surgery	Response rate: 92% Adherence: 69% Adverse events: none reported	Prospective randomized open blinded end point controlled trial	Before and 1 year after surgery

	postoperative outcome.					
Lee et al., 2019a (46); Lee et al., 2019b (45); Lee et al., 2020 (47) ,	Determine whether a HIIT intervention is a feasible exercise strategy for breast cancer patients undergoing anthracycline-based chemotherapy.	Participants: 30 Age: 46.9 (± 9.8) Gender: Female	Type: Breast Stage: II & III Treatment: anthracycline-based chemotherapy	Response rate: 100% Adherence: 82.3% Adverse events: none	Randomised pilot feasibility trial	8-week HIIT intervention occurring 3 times weekly
MacDonald et al., 2021 (36)	To examine physical and immunological changes, and feasibility of a 12-week high-intensity interval training (HIIT) combined with muscle endurance-based resistance training on older adults with treatment naïve CLL.	Participants: 18 Age: 64.9 (± 9.1) Gender: 8 male, 8 female	Type: chronic lymphocytic leukemia (CLL) Stage: Rai stage 0 or 1 Treatment: nil	Response rate: 88% Adherence: 99% Adverse events: none	Two-arm, quasi-experimental pilot study	HIIT consisted of three 30-min treadmill sessions/week plus two concurrent 30-min strength training sessions/week for 12 weeks.
MacVicar et al., 1989 (48)	The effect of aerobic interval training on functional capacity.	Participants: 45 Age: 45 Gender: Female	Type: Breast Stage: II Treatment: Chemotherapy	Response rate: 73% Adherence: NA Adverse events: none	Pilot study	10 weeks, 3 times per week exercise training
Mijwel et al., 2018a (49); Mijwel et al., 2018b (50); Mijwel et al., 2018c (51); Mijwel et al., 2019 (52); Wiggenraad et al., 2020 (53); Hiensch et al., 2021 (54); Bolam et al., 2019 (55)	To compare the effects of resistance and high-intensity interval training (RT–HIIT), and moderate-intensity aerobic and high-intensity interval training (AT–HIIT) to usual care (UC) in women with breast cancer undergoing chemotherapy on CRF and the secondary endpoints were HRQoL and cancer treatment-related symptoms.	Participants: 240 Age: 53 (10.3) Gender: Female	Type: Breast Stage: I–IIIa Treatment: chemotherapy	Response rate: 76% Adherence: 83% in the RT–HIIT group and 75% in AT–HIIT group Adverse events: none	Randomised controlled trial	Baseline and 16 weeks data collection, exercise sessions in an exercise clinic twice weekly for 16 weeks, duration was approximately 60 min
Morielli et al., 2021 (56)	To evaluate the effects of exercise on symptom management and quality of life in rectal cancer patients receiving neoadjuvant	Participants: n=36 Age: 57 ± 12 Gender: 67% male	Type: Rectal Stage: 23 (64%) participants had stage III disease (other stages not reported) Treatment: scheduled to receive standard long-course	Response rate: 64% Adherence: median=82% (IQR=65–95%) Adverse events: no adverse events	Two-armed, phase II randomized controlled trial w	(1) baseline (pre-NACRT), (2) post-NACRT, and (3) pre-surgery.

	chemoradiation (NACRT).		NACRT consisting of 5–6 weeks of radiation therapy (45–54 Gy) with concurrent chemotherapy (oral capecitabine or intravenous 5-fuorouracil) followed by total mesorectal excision			
Northey et al., 2019 (66)	To investigate the effects of two exercise interventions on cognitive function amongst breast cancer survivors.	Participants: n=17 Age: 62.9 ± 7.8 years Gender: 100% female	Type: breast Stage: I-III Treatment: Post-treatment	Response rate: 55% Adherence: HIIT: 78.7% MOD: 79.4% Adverse events:	Pilot randomised -controlled trial	Baseline 12 weeks
Ochi et al., 2022 (67)	To determine whether the newly developed habit-B programme, which involves home-based smartphone-supported HIIT using body weight exercises, improves CRF in early-stage breast cancer survivors.	Participants: n=50 Age: Intervention: 48±6 Control: 49±5 Gender: 100% female	Type: breast Stage: I–IIa Treatment: completed initial treatment except for hormone therapy	Response rate: 4% Adherence: 86% (range 19%–100%) Adverse events: No serious (grade ≥3) adverse events occurred.	Single-blind, randomised controlled trial	Baseline 12 weeks
Papadopoulos et al., 2021 (37)	To assess the feasibility of 8 weeks of HIIT and RT versus usual care (UC) in men with prostate cancer on active surveillance.	Participants: 18 Age: Mean 62.5 (range: 44–71) Gender: 100% male	Type: Prostate Stage: Early stage Treatment: currently on active surveillance	Response rate: 16% Adherence: RT: 96% HIIT: 96% Adverse events: One participant from each exercise group reported acute knee discomfort after a training session; however, no symptoms were reported at their subsequent visits and participants	3-arm feasibility randomized controlled trial	Baseline 8 weeks

				were able to complete the intervention. No serious adverse events were reported.		
Persoon et al., 2017 (68)	To determine the effectiveness of an individualised high intensity supervised exercise program on physical fitness (i.e. cardiorespiratory and muscular fitness) and fatigue in a relatively homogeneous sample of patients with multiple myeloma or lymphoma recently treated with auto-SCT.	Participants: n=109 Age: Median= 55 years (range 19–67) Gender: Intervention = n=32 (59%) Control= n=37 (67%)	Type: Hematologic malignancy Stage: Not reported Treatment: 6–14 weeks post autologous stem cell transplantation	Response rate: 24% Adherence: Intervention group attended on average 25.8 (SD = 3.8) of the prescribed 30 exercise sessions Adverse events: n=4 serious adverse events in the intervention group (not described); n=1 calf muscle strain during exercise (minor) n=4 serious adverse events in the usual care group (not described)	Single blind RCT	Baseline 18 weeks
Piraux et al., 2021 (57)	To investigate the comparative effectiveness of HIIT and RES compared to UC on CTRF, QoL, depression, daytime sleepiness, insomnia, sleep quality, functional exercise capacity and executive function in PCa patients undergoing RT.	Participants: n=78 Age: 69.1 ± 8.2 years Gender: 100% male	Type: prostate Stage: Not reported Treatment: undergoing radiotherapy	Response rate: 88% Adherence: HIIT=93.5%, RES=91.4% Adverse events: no exercise-related adverse events were recorded	three-arm RCT	Baseline Post Radiation therapy (5-8 weeks)
Piraux et al., 2022 (58)	To determine the feasibility of HIIT and RES in rectal cancer patients undergoing neoadjuvant chemoradiotherapy (NACRT).	Participants: n=18 Age: median age of 62.0 (59.8 to 68.8) years Gender: male (72%)	Type: rectal Stage: II-III Treatment: undergoing chemoradiotherapy	Response rate: 78% Adherence: 92% in HIIT and 88% in RET Adverse events: No exercise-related adverse events occurred	three-arm, randomized controlled study	Baseline Week 5
Reljic et al., 2022 (59)	To investigate feasibility, safety, and preliminary efficacy of very low-volume HIIT (LOW-HIIT) in	Participants: n=27 Age: 55.4 ± 13.2 yr Gender: HIIT: 54% male	Type: Advanced Cancer Patients Stage: III-IV Treatment: ongoing anticancer therapy	Response rate: 90% Adherence:92.5% (LOW-HIIT group), 97.3% (SHAM group) Adverse events:	Randomized, sham-intervention controlled study	Baseline 12 weeks

	advanced cancer patients.	SHAM: 43% male		HIIT: Knee pain n=1 Nausea n=3 Vomiting n=1 Diarrhea n=2 Extreme fatigue n=1 Cystitis n=1 SHAM: Knee pain n=1 General muscle pain n=3 Muscle cramps n=6 Nausea n=1 Circulatory problems n=2 Nausea n=8 Vomiting n=3 Diarrhea n=1 Extreme fatigue n=5 Cystitis n=2		
Samhan et al., 2021 (69)	To evaluate the effects of HIIT on cardiorespiratory fitness and body composition in survivors of breast cancer who are overweight and obese.	Participants: n=60 Age: HIIT: 49.7 ± 8.9 Control: 48.9 ± 7.7 Gender: 100% female	Type: Breast Stage: I-III Treatment: Post-treatment	Response rate: 86% Adherence: Not reported Adverse events: There were no adverse events or complications related to exercise testing or intervention.	2-arm, randomized-controlled, double-blinded study	Baseline 8 weeks
Schulz et al., 2018 (70)	To evaluate feasibility of an exercise intervention consisting of high-intensity interval endurance and strength training in breast cancer patients.	Participants: n=26 Age: 51.9 ± 9.8 years Gender: 100% female	Type: Breast Stage: I-III Treatment: Post-treatment and during treatment (chemotherapy, radiotherapy, hormone therapy)	Response rate: Not reported. Adherence: 73% completed 12 sessions, 20% completed 11 sessions and 7% completed 10 sessions. Adverse events: No training-related adverse events were observed.	Two-armed cohort pilot study	Baseline 6 weeks
Sommer et al., 2016 (60)	Investigate safety and feasibility of preoperative and early postoperative rehabilitation in a nonhospital setting, focussing on exercise, in patients undergoing surgery for lung cancer.	Participants: 40 Age: 68y (SD not reported) Gender: Male 16, Female 24	Type: Non-small cell lung. Stage: Stage 1 (11), Stage 2 (24), Stage 3A (5) Treatment: Surgical resection.	Response rate: Adherence: Preoperative exercise (67%), postoperative exercise (73%) Adverse events: Nil	Randomised controlled trial	Baseline, post-intervention, and at 12 months.
Toohey et al., 2018 (14)	Investigate and compare the effects of low volume high-	Participants: 75 Age: 51.48y (12.45)	Type: Breast (47), Ovarian (2), appendix (1), anal (1), cervical	Response rate: Adherence: 76% of participants	Randomised controlled trial	Baseline and 12 weeks.

	intensity interval training and continuous low to moderate-intensity training on improving health outcomes and reducing cardiovascular disease risk in cancer survivors.	Gender: Female	(1), liver (1), oesophageal (1), Melanoma (1), leiomyosarcoma (1), unknown primary (1) Stage: Stage I-II (45), Stage II-IV (12). Treatment: Surgery (53), radiation therapy (41), hormone therapy (43), chemotherapy (43), no chemotherapy (14).	completed the study. Adverse events: Nil.		
Toohey et al., 2020 (16)	Explore the impact of high-intensity interval training on cardiovascular fitness and markers of cardiac regulation, sympathetic nervous system activity, HPA axis, and mucosal immunity in breast cancer survivors.	Participants: 17 Age: 62y (8) Gender: Female	Type: Breast Stage: Post cancer treatment. Treatment: Surgery (1), radiation (1), surgery plus chemotherapy (1), surgery plus radiation (8), surgery plus chemotherapy plus radiation (6).	Response rate: Adherence: High intensity interval training 78.7% (13.2), Moderate intensity continuous aerobic training 79.4% (12.0%). Adverse events: Nil.	Pilot randomised controlled trial	Baseline, 2-4 days pre-intervention, and 2-4 days post-intervention.

Supplementary 4. A brief overview of HIIT prescription used in the interventions.

Author	HIIT Prescription
Adams et al., 2017 (61); Adams et al., 2018 (62)	· 5-minute warm-up (performed at 65% of the ventilatory threshold calculated from a maximal exercise test) · 5-min cooldown · Total of 35-minute session · During the work period, participants completed 4 high-intensity intervals – 4 mins each · Progressed from 75% to 95% of VO2peak over the intervention period · High-intensity intervals were separated by 3-min active recovery intervals (performed 5%-10% below the ventilatory threshold)
Alizadeh et al., 2019 (38)	· Exercise intervals consist of 4 × 4 min of uphill walking at 90–95% HRmax (exercise) and 4 × 3 min of uphill walking at 50–70% HRmax (active recovery) · Overall time of each session duration was 38 mins · 5 min warm-up, 5 min cool down, 16 min of high-intensity intervals and 12 min of active recovery
Ansund et al., 2021 (39)	· RT-HIIT group performed resistance training consisting of 8–12 repetitions at 75–80% of 1RM · targeting the major muscle groups · Followed by 3 × 3 min bouts of aerobic high intensity interval training (HIIT) on a cycle ergometer · AT-HIIT group started each session with 20 min of moderate intensity continuous aerobic exercise, followed by the same HIIT regimen (described above)
Baguley et al., 2022 (40)	· Exercise intensity was set at 85–95% HRpeak and each 4-min interval was interspersed with 3-min of active recovery at 50–70% HRpeak. · Heart rate zones of 50–70% and 85–95% were individually determined from the highest HR recorded during a VO2peak test at 12 weeks. · The HIIT sessions commenced with 10 min of warm up at 50–70% HRpeak before participants completed 4 x 4-min bouts of cycling
Banerjee et al., 2018 (26)	· Sessions comprised of vigorous intensity aerobic interval exercise on a cycle ergometer using the Borg Ratings of Perceived Exertion (RPE) Scale to control intensity · 5–10-min warm-up against light resistance (50 W), · 6 × 5 min intervals at a target perceived exertion of 13–15 (‘somewhat hard’ to ‘hard’, equating to 70–85% predicted maximum heart rate based on 220-age) · 2.5 min interpolated active rest intervals against light resistance (50 W) in between · They were instructed to maintain a steady pedalling cadence of 50– 60 rev min−1 during the aerobic intervals, and the exercise programme was progressed by gradually adding more load to maintain the target perceived exertion · Immediately following the aerobic intervals, patients performed a ‘cool-down’ against low resistance (50 W)
Bhatia et al., 2019 (27)	· Pedalling rate was 60–70 revolutions per min (RPM) · 5-min warm-up at 50% Wpeak, · 15-s sprints at 100% Wpeak interspersed by 15 s of passive resting periods, for 2 series of 10 min, with a 4-min rest period in between · 5-min cool-down at 30% Wpeak
Blackwell et al., 2020 (28)	· 2-min warm-up period of unloaded cycling, · 5, 1-min exertions at 100–115% of the maximal load (watts (W)) reached during their initial CPET · 2-min recovery period of unloaded cycling. · An increase in wattage was implemented at the mid-way point of training to maintain exercise intensity with progression
Devin et al., 2018 (63)	· 10-minute warm-up at 50% to 70% HRpeak · 4 x 4 mins; 85%-95% HRpeak, · 3 mins rest in between · Total 38 min session
Dimeo et al., 1997 (41)	· 1 min at least 50% of the cardiac reserve, followed by 1 min rest x 15 · A total of 30 mins each day
Djurhuus et al., 2022 (29)	· Light warm-up was followed by 20–25 min of aerobic HIIT · HIIT consisted of 4–6 cycles of high intensity intervals for 1 min at 100–120% of peak power output (Wpeak) · Followed by 3 min of active recovery at 30% of Wpeak

Dolan et al., 2016 (64)	· 2 weeks of introductory intervals at a maximal intensity of 80 % VO2peak, · Followed by progressively higher intensity interval bouts for 4 weeks, eventually requiring 2 min efforts that would elicit close to a maximal effort · Week 1 50% VO2peak · Week 5 95% VO2peak
Dunne et al., 2016 (30)	· Warm-up and warm-down · 30min of interval training alternating between exercise of moderate (less than 60 per cent VO2 at peak exercise) and vigorous (more than 90 per cent VO2 at peak) intensity
Egegaard et al., 2019 (42)	· 5-minwarm-up phase followed by three 5-min exercise phases · Warm-up consisted of light stationary cycling, individually adjusted to 50–60% of the patient's peak power output deter-mined at the incremental cycle test · The first and the third exercise phase comprised of interval training consisting of 5 × 30s intervals at 80–95% of the incremental cycle test (iPPO) · Each interval separated by a 30s pause · The second exercise phase consisted of continuous cycling at an intensity equalling 80% of the patient's iPPO · Over the 7 weeks, the intensities were increased progressively from 50%, 80%, 70% and 80% of iPPO to 60%, 95%,80% and 95% of iPPO according to the four phases
Gonzalo-Encabo et al., 2022 (43)	· Exercise sessions began with a warm-up (5 min, 10% PPO) · Immediately followed by the HIIT protocol (20 min) consisting of 7 high intensity bouts (1 min) of exercise (90% peak power output (PPO)) with active recovery (2 min, 10% PPO)
Hooshmand Moghadam et al., 2021 (65)	· 20 min of moderate-intensity aerobic exercise at an RPE of 13–15, · Followed by 3 x 3-min bouts of high-intensity intermittent aerobic exercise at an RPE of 16–18 interspersed with 1 min low-intensity active recovery
Hwang et al., 2012 (44)	· Exercise training consisted of 2–5-min intervals, alternating with high intensity [80% VO2peak, or a rate of perceived exertion (RPE) of 15–17], · Active recovery of moderate intensity (60% VO2peak, or a RPE of 11–13) · Each exercise session was 30–40 min in length, including 10-min warm-up and 5-min cool-down phases
Kang et al., 2021 (35); Kang et al., 2022a, (33); Kang et al., 2022b (34)	· HIIT session comprised 2 mins of high-intensity exercise (workload corresponding to 85-95% peak oxygen consumption [VO2peak]) · Followed by 2 mins of light-intensity exercise recovery (workload corresponding to 40% VO2peak) · With progression from 5 to 8 intervals resulting in 28 mins to 40 mins of exercise (including warm-up and cool-down for 5 mins each)
Karenovics et al., 2017 (31); Licker et al., 2017 (32)	· 5-min warm-up period at 50% of peak work rate (WRPeak) achieved during CPET · The patients then completed two 10 min long series of 15 s sprint intervals (at WRPeak, 'all-out' effort) interspersed by 15 s pauses and a 4-min rest between the 2 series. · The patients then cooled down with a 5-min active recovery period at 30% WRPeak
Lee et al., 2019a (46); Lee et al., 2019b (45); Lee et al., 2020 (47) ,	· HIIT training session included 7 times of a 1-min interval performed at 90% PPO followed by a 2-min interval performed at 10% PPO · 5-min warm-up performed at 10% PPO followed by the 20-min HIIT protocol (90% PPO/10% PPO), and then a 5-min cool-down (10% PPO)
MacDonald et al., 2021 (36)	· 5-min warm-up and 5-min cool down as part of the total session. · Intervals were designed to elicit a heart rate corresponding to 80–90% of VO2 reserve (high intensity intervals) and 50–60% VO2 reserve (active recovery)
MacVicar et al., 1989 (48)	· Specific details not reported
Mijwel et al., 2018a (49); Mijwel et al., 2018b (50); Mijwel et al., 2018c (51); Mijwel et al., 2019 (52); Wiggenraad et al., 2020 (53); Hiensch et al., 2021 (54); Bolam et al., 2019 (55)	· 5-min warm up on a cycle ergometer or treadmill at a rating of perceived exertion (RPE) of 10–12 on the Borg scale, and ended with a 10-min cool down of dynamic muscle stretching · 20 min of moderate intensity, continuous aerobic exercise at an RPE of 13–15on a cycle ergometer, elliptical ergometer, or treadmill · 3 × 3-min bouts of high intensity interval aerobic exercise on a cycle ergometer at a rating of perceived exertion of 16–18 on the Borg scale interspersed with one min of low-intensity active recovery

Morielli et al., 2021 (56)	· 5-min warm-up · Eight 2-min high-intensity intervals (85% of VO2peak) · Interspersed with 2-min low-intensity active recovery intervals (40% of VO2peak) · 5-min cool-down
Northey et al., 2019 (66)	· 5-min warm-up and cool-down at 50% of their peak power · Participants initially (week 1) completed four intervals lasting 30 s with 2 min of active recovery · The number of intervals was increased by one each week until the target of seven intervals was achieved in week 4. · The number of intervals were maintained at seven for the remainder of the intervention. HIIT participants were instructed to increase their pedalling rate to between 95 and115 revolutions per minute (RPM) to ensure a consistent and maximal effort across each interval. · The resistance was adjusted by the supervisor over the intervention for each participant to ensure they remained within the 95–115 RPM range and reached a heart rate above 90% of their maximum by the fourth interval. · The active recovery was performed with a light resistance at a self-selected pedalling rate.
Ochi et al., 2022 (67)	· A total of 10 min exercise · Comprising a 3 min warm-up, 4 min training (8 sets of 20 s exercise +10 s rest), and a 3 min cool-down
Papadopoulos et al., 2021 (37)	· 10 x 60 seconds at ≥85% of peak heart rate (HRpeak) based upon the baseline CPET interspersed with 60 seconds of active recovery (15W) · Commenced with a 3-min warm-up period and · Concluded with a 2-min cool-down · Total exercise time of 25 mins per session. · The first and second weeks of HIIT involved 6 and 8 high intensity intervals · From week 2 to 8, participants performed 10 high-intensity intervals per session
Persoon et al., 2017 (68)	· Two times eight mins of cycling · Blocks of 30s at 65% maximal short exercise capacity (MSEC) were alternated with blocks of 60s at 30% MSEC
Piraux et al., 2021 (57)	· 5 min warm-up at an intensity of 65–70% of the theoretical maximal heart rate · (THRmax = 220 − age) · 8 × 60 s sessions at ≥85% THRmax interspersed by 60s interval rest at a slow intensity · 5-min cool down
Piraux et al., 2022 (58)	· Cycle ergometer with a work-recovery ratio of 1:1 with a 60-s work interval at a cadence range of 90–100 revolutions per min at ≥ 85% of the theoretical maximal heart rate (THRmax = 220 – age) interspersed by 60-s active rest unloaded, at a cadence range of 50–60 revolutions per minute · Warm-up and cool-down were done at 65–70% THRmax for 5 min each
Reljic et al., 2022 (59)	· 2-min warm-up period · Followed by five interval bouts of 1 min at 80% to 95% HRpeak interspersed with 1 min of low intensity recovery · Concluding 3 min cooldown phase (total time per session, 14 min)
Samhan et al., 2021 (69)	· HIIT training session was conducted for 38 minutes, · Beginning with a 5-min warm-up exercise to increase the HR to a maximum of 50% to 70% (HRmax) followed by the effort time, and finished with a 5-min cooldown period · Four x 4-min high-intensity intervals, during which the intensity of exercise training was increased progressively to attain 75% to 90% of the HRmax; it was maintained over the effort time · Every 4-min high-intensity interval was followed by a 3-min active regaining interval (executed at 50%-60% of the HRmax)
Schulz et al., 2018 (70)	· 10 repetitions of one-min peak loads at 85–100% of VO2,peak, separated by one-min load-less intervals · This was framed by a 15-min warm-up, a 3-min cool down both at 50% of VO2,peak · Total duration of HIT was 39 min
Sommer et al., 2016 (60)	· Warmup period where the participants aimed at reaching a level at 85% of individually determined HRmax (5 mins) · Followed by a short rest (1 min) · The duration of the high intensity interval exercises was 25 mins · In each interval (1-2 mins), the participants aimed at reaching a level of 85% to 100% of individually determined HRmax in each interval followed by a short rest (1 min) · The high-intensity interval exercise was followed by a cool down period (2 mins)
Toohey et al., 2018 (14)	· Interval training (≥ 85% maximal heart rate), which consisted of a five-min warm up, seven by 30 s intervals, with one-min rest in between each interval · Followed by a five-min cool down

Toohey et al., 2020 (16)	· The HIIT group completed 7 x 30 s intervals (as hard as they could) with 2 min of active recovery between each · Participants were instructed to increase their cadence to between 95 and 115 RPM to ensure consistent performance and reached a heart rate above 90% of their maximum by the fourth interval · Participants initially completed four intervals in each session, and this was gradually increased to achieve the target of seven intervals by week four

Supplementary 5. Outcome measures used in included studies.

Author/Year	Data Collection Tools
Adams et al., 2018 (61)	· Exercise capacity (Vo2) · Cardiovascular function (BP, PWV) · Blood biomarkers (Endothelial and inflammatory markers fibrinogen, c-reactive protein blood lipids, Metabolic and gonadal function, fasting glucose, testosterone) · CVD risk factors: Framingham, vascular age, modifiable risk factors
Adams et al., 2017 (62)	· Godin Leisure Time Exercise Questionnaire, Functional Assessment of · Cancer Therapy Fatigue scale (FACT – F), Center for Epidemiologic Studies Depression Scale, Spielberger State Anxiety Scale, Perceived Stress Scale, Rosenberg Self- · Esteem Scale, Pittsburgh Sleep Quality Index, SF-36 & Vo2
Alizadeh et al., 2019 (38)	· Weight, BMI, skin folds · Rockport 1-mile walk test · Blood sampling (serum inflammatory markers, cytokine assays)
Ansund et al., 2021 (39)	· Objectively measured sedentary behaviour and physical activity were assessed by accelerometer (model GT3X ActiGraph) and estimated VO2peak, as a proxy for cardiorespiratory fitness (CRF) was assessed using the Åstrand Rhyming submaximal cycle test · Biomarkers (cardiac Troponin T, NT-pro-BNP, Plasma cTnT)
Baguley et al., 2022 (40)	· HR, BP, Vo2 peak, · Height, body mass (dual energy X-ray absorptiometry), body composition (dual energy X-ray absorptiometry), · Intervention fidelity, fatigue (FACIT), medical outcomes (SF36), dietary intake (Wollongong Dietary Inventory)
Banerjee et al., 2018 (26)	· Feasibility was assessed in terms of recruitment and attrition, willingness to be randomised, acceptability of the outcome measures, adherence to the intervention, safety and suitability of the exercise dose and adverse events · Cardiopulmonary exercise test (CPET), Clavien-Dindo grading was used to score post-surgical complications
Bhatia et al., 2019 (27)	· Cardiopulmonary testing (6-minute walk test – at enrolment, CPET according to ATS/ERS standards – after enrolment and at the end), Work-rate, heart rate · Saturation (SpO2res), dyspnoea (Dysp, Borg 0–10 scale) and leg effort
Blackwell et al., 2020 (28)	· Anaerobic threshold (VO2AT), BP, Dukes Activity Status Index · (DASI), EuroQol Group 5-level (EQ-5D-5L), Warwick Edinburgh Mental Wellbeing Scale (WEMWBS), dual energy X-ray absorptiometry (DXA), vastus lateralis was measured using B-mode ultrasonography
Bolam et al., 2019 (55)	· Two years after baseline data collection to assess cancer-related fatigue (Swedish version of the revised Piper fatigue Scale (PFS)), · Quality of life (Swedish version of the European Organisation for Research and Cancer Treatment Quality of Life Questionnaire (EORTC-QLQ-C30)), · Symptoms Swedish version of the Memorial Symptom Assessment Scale (MSAS)) · Muscle strength ((Baseline leg dynamometer, Fabrication · Enterprises Inc., White Plains, NY, USA) and hand grip tests (JAMAR, SAEHAN corporation, Changwon, S. Korea)), · Cardiorespiratory fitness Åstrand-Rhyming submaximal cycle test (Monark 928E, Monark Exercise AB, Vansbro, Sweden)), body mass (calibrated electric scales), PA (accelerometer), sedentary behaviour (accelerometer), and sick leave (single item Questionnaire), general medical history and participant demographics were recorded by questionnaires
Devin et al., 2018 (63)	· V_ O2peak (cycle ergometer (Lode Excalibur Sport; Lode, Groningen, The Netherlands) and a portable metabolic cart system (TrueOne 2400; Parvo Medics, Sandy, UT)), · Lean and fat mass (dual-energy x-ray absorptiometry), height and body mass (stadiometer (Seca, Birmingham, UK) and electronic scales (A & D Mercury, Thebarton, Australia))
Dimeo et al., 1997 (41)	· Aerobic fitness (treadmill test - stress-test under continuous ECG monitoring (starting at 3 km/h and 1.5% elevation, acceleration of 1 km/h every third minute by unchanged elevation and continued until exhaustion) · Blood counts and serum chemistry (including evaluation of hepatic and renal function) were carried out daily, · Hematologic and nonhematologic toxicity were analyzed according to WHO criteria
Djurhuus et al., 2022 (29)	· Natural killer-cell infiltration · Cardiorespiratory fitness (VO_{2peak}) · Fasting blood samples (cholesterols, triglycerides, glucose, insulin, C-peptide, haemoglobin, HbA_{1c}, PSA) · PROMs (FACT-P, HADS)

Dolan et al., 2016 (64)	· Change in VO_{2peak} · Body composition · Resting heart rate · Lower body muscular strength (1RM)
Dunne et al., 2016 (30)	· Anaerobic threshold (CPET), VO2 at anaerobic threshold, VO2 at peak, Oxygen pulse at anaerobic threshold, oxygen pulse at peak, peak work rate, heart rate reserve · SF-36
Egegaard et al., 2019 (42)	· Aerobic capacity (VO_{2peak}) · Functional capacity (6-min walk test) · Lung function (forced expiratory volume in 1 s – FEV_1) · Wellbeing (HADS) · QoL (FACT-L)
Gonzalo-Encabo et al., 2022 (43)	· Metabolic syndrome (3 or more of the risk factors: waist circumference ≥88 cm, systolic blood pressure ≥130 mmHg, diastolic blood pressure ≥85 mmHg, fasting levels of high-density lipoprotein cholesterol (HDL-C) <50 mg/dL, triglycerides ≥150 mg/dL, and glucose ≥100 mg/dL.) · Serum biomarkers (glucose, HDL-C, low-density lipoprotein cholesterol (LDL-C), total cholesterol, triglycerides, and glycosylated hemoglobin (HbA1c)) · Anthropometrics (weight, height, waist circumference, hip circumference, body composition, blood pressure)
Hiensch et al., 2021 (54)	· Inflammatory markers · Cancer-related fatigue (Piper Fatigue Scale) · Physical activity measurements: muscle strength (hydraulic hand dynamometer), lower-limb muscle strength (isometric midthigh pull), cardiovascular fitness (VO_{2peak} on a cycle)
Hooshmand Moghadam et al., 2021 (65)	· Anthropometrics and body composition (body mass, height, BMI, lean mass) · Blood analysis (serum IL-8, IL-10, IL-6, TNF-α, leptin, adiponectin) · Physical fitness (VO_{2peak}, upper and lower body strength using one-repetition maximum)
Hwang et al., 2012 (44)	· Cardiopulmonary exercise testing (VO_{2peak}) · Muscle oxygenation (near-infrared spectroscopy) · Isokinetic muscle testing (isokinetic dynamometer) · Insulin resistance · Inflammatory response (high sensitivity C-reactive protein) · QoL (EORTC QLQ-C30)
Kang et al., 2022a (33)	· Motivation: anticipated (baseline) and experienced (postintervention); Theory of Planned Behaviour items · Anticipated and experienced outcomes: asked relating to prostate cancer outcomes following a HIIT intervention · Perceived barriers of the HIIT intervention: 14-item questionnaire · Current exercise behaviour: Godin Leisure Time Exercise Questionnaire
Kang et al., 2021 (35)	· Cardiorespiratory fitness (VO_{2peak}) · Serum prostate-specific antigen concentration · Sex hormone levels · Functional fitness (Senior Fitness Test) · Anthropometrics
Kang et al., 2022b (34)	· Prostate cancer-specific anxiety: Memorial Anxiety Scale for Prostate Cancer · Fear of cancer progression: Fear of Cancer Recurrence Inventory short-form and Cancer Worry Scale · Prostate cancer symptoms: Expanded Prostate Cancer Index Composite-26 · QoL: EORTCQLQ-C30 · General anxiety: Spielberger State-Trait Anxiety Inventory · Depression: Center for Epidemiologic Studies-Depression Scale · Fatigue: Functional Assessment of Cancer Therapy-Fatigue Scale · Stress: Perceived Stress Scale · Self-esteem: Rosenberg Self-Esteem Scale
Karenovics et al., 2017 (31)	· Cardiopulmonary exercise testing (CPET - symptom-limited CPET preceded by pulmonary function tests) · Pulmonary functional tests (PFTs) including forced vital capacity (FVC), forced expiratory volume (FEV1) and carbon monoxide transfer factor (KCO) were performed. · Demographic and clinical data, diagnostic information, any comorbidities and results of lung functional and blood laboratory tests. · Surgical and anaesthetic data were extracted from the electronic · Patient Data Management System.

Lee et al., 2019a (46)	· Peak power output during maximal oxygen uptake (VO2max), feasibility was calculated by computing (1) the average weekly minutes of HIIT over 8 weeks and (2) the number of sessions attended and multiplied by 100 (percentage of sessions)
Lee et al., 2020 (47)	· Matrix metalloproteinases (MMP)-1, -2 -7, -9, tissue inhibitor of MMP (TIMP) -1, and-2 were measured at baseline and post-intervention
Lee et al., 2019b (45)	· Brachial artery flow-mediated dilation (baFMD), and vascular wall thickness measured by carotid intima media thickness (cIMT)
Licker et al., 2017 (32)	· Maximal cardiopulmonary exercise testing and the 6-minute walk test were performed twice before surgery. · The primary outcome measure was a composite of death and in hospital postoperative complications
MacDonald et al., 2021 (36)	· Aerobic capacity (VO2peak cardiopulmonary exercise test (CPET)), · Muscle strength and endurance (machine-weights—leg press, chest press, and seated row – 1RM) · PA (y 7-day continuous wear of a wrist-based accelerometer (Garmin Vivosmart 3, Garmin, Kansas, USA) · Natural killer (NK) cell recognition and killing of tumor cells
MacVicar et al., 1989 (48)	· VO2Lmax
Mijwel et al., 2018a (49)	· CRF and the secondary endpoints were HRQoL and cancer treatment-related symptoms (Piper Fatigue Scale, EORTC-QLQ-C30, and Memorial Symptom Assessment Scale)
Mijwel et al., 2018b (50)	· Cardiorespiratory fitness (predicted peak oxygen uptake (VO2peak), was assessed by the Åstrand-Rhyming submaximal cycle test) · Muscle strength (handgrip, isometric mid-thigh pull), body mass, hemoglobin levels (venous blood), and pressure-pain threshold (Pressure pain threshold (PPT) was measured bilaterally on the middle trapezius and gluteus muscles with an electronic algometer)
Mijwel et al., 2018c (51)	· Resting skeletal muscle biopsies were obtained pre- and post-intervention
Mijwel et al., 2019 (52)	· CRF (Piper Fatigue Scale) · HRQoL (EORTC-QLQ-C30) · Symptom Burden (MSAS), muscle strength (handgrip, isometric mid-thigh pull), cardiorespiratory-fitness (predicted peak oxygen uptake (VO2peak), was assessed by the Åstrand-Rhyming submaximal cycle test) · Body mass · Return to work (sick leave taken over 12 months)
Morielli et al., 2021 (56)	· Symptoms (MDASI) · Quality of life EORTC QLQ-C30 and QLQ-CR29
Northey et al., 2019 (66)	· Cognitive performance (CogState battery) · Words recalled (International Shopping List) · Episodic memory (Groton Maze Learning Task) · Working memory (One-Back Test) · Cerebrovascular function (resting cerebral blood flow and reactivity to CO2 of mean flow) · Aerobic fitness (exercise test)
Ochi et al., 2022 (67)	· Cardiorespiratory fitness (VO2peak, cycle ergometer test and 6 min walk test) · 1RM for leg press · Grip strength · Chair stand test · Physical activity levels (Global Physical Activity Questionnaire score) · Fatigue (Cancer Fatigue Scale and health- related QOL)
Papadopoulos et al., 2021 (37)	· Feasibility (recruitment, attendance, compliance, retention, and adverse events) · Upper and lower body strength (1RM, seated row, chest press, and leg press) · Body composition (a bioelectrical impedance scale) · Cardiorespiratory fitness (oxygen uptake; mL/kg/min) · Blood markers · Health-related QOL (Functional Assessment of Cancer Therapy- Prostate (FACT-P)). · Anxiety (Memorial Anxiety Scale for prostate cancer (MAX-PC) and Hospital Anxiety and Depression Scale (HADS)) · Fear of disease progression (Fear of Progression Questionnaire - Short Form · (FOP-Q-SF)) · Physical activity (Godin-Time Leisure Exercise Questionnaire)
Persoon et al., 2017 (68)	· Cardiorespiratory fitness (cycle ergometer CPET) · Muscular fitness (grip strength; 3 sec sit to stand) · Fatigue (Multidimensional Fatigue Inventory)

	· Body mass index; Body fat (sum of four skinfolds), maximal isometric voluntary torque of the quadriceps (Biodex)
Piraux et al., 2021 (57)	· Fatigue (FACIT-F), cancer-related QoL (FACT-G), · Depressive symptoms (Centre for Epidemiologic Studies Depression Scale (CES-D), · Daytime sleepiness (Epworth Sleepiness Scale (ESS)), · Insomnia (Insomnia Severity Index (ISI), · Sleep quality (Pittsburgh sleep quality index (PSQI)), · Functional capacity ((6MWT), · Cognitive function (trail-making test)
Piraux et al., 2022 (58)	· Feasibility (recruitment, adherence, and safety) · Fatigue (FACIT–F) · Quality of life (FACT–G) · Depressive symptoms (CES-D) · Daytime sleepiness (Epworth Sleepiness Scale (ESS)) · Insomnia Severity Index (ISI) · Pittsburgh sleep quality index (PSQI)
Reljic et al., 2022 (59)	· Body weight (kg) · Skeletal muscle mass (kg) · Fat mass (%) · Total body water (L) · Extracellular water (L) · Absolute VO˙ 2peak (L·min−1) · Relative VO˙ 2peak (mL·kg−1 ·min−1) · Absolute peak power output (W) · Relative peak power output (W kg−1) · VT (mL·kg−1 ·min−1) · Erythrocytes (μL−1) · Haemoglobin (g·dL−1) · Haematocrit (%) · Leucocytes (μL−1) · Thrombocytes (μL−1) · Glucose (mmol·L−1) · Triglycerides (mmol·L−1) · Total cholesterol (mmol·L−1) · HDL cholesterol (mmol·L−1) · LDL cholesterol (mmol·L−1) · CRP (mg·dL−1)
Samhan et al., 2021 (69)	· Cardiorespiratory Fitness (treadmill VO˙ 2peak test) · Body Composition (bioelectrical impedance analysis scale)
Schulz et al., 2018 (70)	· Cardiopulmonary exercise testing (Vo2peak) · Strength (1RM) Leg press, Rowing machine, One-legged leg stretcher, Lat pulldown, Chest press, total strength · Anxiety and depression (HADS)
Sommer et al., 2016 (60)	· Anthropometric data and tumour node metastasis (TNM), · Maximal oxygen update (Vo2Peak), 6-munute walk distance (6MWD), · 1 repetition maximum (1RM) muscle strength test, · Pulmonary function test – forced expiratory volume (FEV), · Functional assessment of cancer therapy-lung (FACT-L).
Toohey et al., 2018 (14)	· Quality of life: Functional Assessment of Cancer Therapy-General Questionnaire (FACT-G) · Anthropometrics: Total body composition (Lean mass, weight, body fat percentage, hip and waist circumference). · Cardiovascular: Pulse wave velocity (PWV) and pulse wave analysis (PWA) including resting heart rate (RHR), augmentation index (stiffness) (AIx), central systolic blood pressure (CSP), central diastolic blood pressure (CDP), central pulse pressure (PP), mean arterial pressure (MAP), systolic blood pressure (SBP), diastolic blood pressure (DBP) · Blood biomarkers: C-reactive protein (CRP), insulin, glucose, full blood count · Functional capacity: Lower body strength - sit-to-stand (STS), Fitness- six-minute walk test (6MWT)
Toohey et al., 2020 (16)	· Cardiovascular fitness (Vo2Peak) · Heart rate variability (LnRMSSD) · Salivary biomarkers (s-AA, s-IgA and s-cortisol)
Wiggenraad et al., 2020 (53);	· Memorial Symptom Assessment Scale

Supplementary 6: Subgroup analyses for the primary outcome (aerobic fitness) comparing effects of cancer type and treatment status.

Subgroup	Intervention arms (n=)	Participants (n=)	Heterogeneity (%)	SMD (95% CI)	P-value
Cancer					
Prostate or testicular	7	254	42	0.67 [0.32, 1.02]	<0.01
Lung	4	341	0	0.52 [0.30, 0.74]	<0.01
Breast	8	311	21	0.70 [0.43, 0.96]	<0.01
Colorectal	3	74	0	0.83 [0.35, 1.31]	<0.01
Urological or bladder	1	60	NA	0.04 [-0.46, 0.55]	0.87
Mixed	3	133	57	0.59 [0.01, 1.17]	0.04
Leukemia/Hematologic	1	109	NA	0.28 [-0.10, 0.65]	0.15
Treatment					
Pre-treatment	7	486	0	0.47 [0.29, 0.65]	<0.01
Post-treatment	10	396	47	0.84 [0.54, 1.14]	<0.01
During treatment	8	265	0	0.59 [0.34, 0.84]	<0.01
During and post-treatment	2	135	0	0.23 [-0.11, 0.57]	0.18
Overall	27	1282	29	0.58 [0.44, 0.72]	<0.01